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Effectiveness of coastal bio-shield for reduction of the energy of storm surges and cyclones

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Abstract

Vegetation bio-shield has been widely recognized as a natural method to reduce the energy of cyclones and storm surges. The effectiveness of coastal vegetation in reducing storm surge has been investigated in this study. This study includes three types of analysis such as satellite image analysis, numerical model simulation and laboratory experiment. In satellite image analysis, two SPOT images are analyzed to investigate the damages caused by the super cyclone SIDR which occured on the 15th of November, 2007. From this analysis it is studied that the densely populated vegetation areas were less damaged than the exposed areas without vegetation barriers. About 3% of the total study area was damaged by the SIDR. A two dimensional hydrodynamic model named Bay of Bengal model was applied for Sandwip island to study the effect of afforestation in reducing storm waves and current speed. Three scenarios of 200m, 400m and 600m distance of vegetation from embankment and two specific points were considered at the east side of Sandwip island. Results show that the water level decreases slightly but the current speed increases significantly as the distance of vegetation barrier increases from the embankment towards the sea. The laboratory experiment shows that the wave height is reduced up to 46% behind the vegetation zone, 43% within the barrier and 41% in front of vegetation for wave period of 1.6 sec when the vegetation barrier is placed at 1m from embankment.

Keywords: Coastal bio-shield; numerical model simulation; laboratory experiment; SPOT image; SIDR.

1.0 Introduction

Coastal vegetation has been widely recognized as a natural method to reduce the energy of storm surges and tsunami waves. However, a vegetation barrier cannot completely stop a tsunami or storm surge and its effectiveness depends on the magnitude of the storm surge as well as the structure of the vegetation. The effectiveness of vegetation also changes with the age and structure of the forest. This highlights the fact that proper planning and management of vegetation are required to maintain the buffering function of coastal forests. An integrated coastal vegetation management system that includes utilization of the materials produced by the forest and a community participation and awareness program are proposed to achieve a sustainable and long lasting vegetation bio-shield.

Bangladesh is one of the most cyclone prone countries in the world. Most of the cyclone affected areas are concentrated in the southern coastal region of Bangladesh. Every year in pre-monsoon periods of April-May and in post-monsoon periods of November-December there is a high potential period for cyclone occurrence. On the 15th of November, 2007 the category-4 cyclone SIDR with a wind speed of 250 km/hr attacked the southern coast of Bangladesh. But the Sundarban, world's richest mangrove forest, acted as a buffering zone and reduced the effects of the SIDR. If the Sundarban was not there, massive devastation would have occured in Bangladesh. In 1584, about 200,000

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people were reportedly killed in Barisal by a cyclonic storm surge. Another cyclone that hit in 1822 killed more than 70,000 people in Barisal and 95 percent population of the Hatia Island. Considering the much smaller populations during those times, the numbers of deaths give an indication to the severity of cyclones. A cyclone in November, 1970 hit the southern districts of Bangladesh forcing a 9m high storm surge and killing approximately 300,000 people (Haider *et al.,* 1991). The cyclone of 1991 caused 138,000 lives. In most recent years, however, numbers of deaths caused by the cyclones with severe intensity have declined due to the growing successful institutional arrangements for disaster management and the fact that there are now over 2000 cyclone shelters spread along the coast.

Dengler and Preuss (2003) investigated the disaster caused by the 1998 Papua New Guinea tsunami and found that casuarina trees presented relatively greater resistance than palm trees. Kathiresan and Rajendran (2005) concluded that the presence of mangroves reduced the human death toll along the Tamil Nadu coast of southeast India, although Kerr et al. (2006) argued that this is an over simplification of a complex scenario. Dahdouh-Guebas et al. (2005) showed by cluster analysis that the man-made structures located directly behind the most extensive mangroves were less damaged. Field surveys in Sri Lanka and Thailand after the Indian Ocean tsunami showed that older casuarina belts on the coast withstood the tsunami but failed to provide good protection (Tanaka et al. 2006a, b, 2007). Tanaka et al. (2007) showed that tree growth and forest density can have a significant effect on tsunami mitigation.

Coastal vegetation acts as buffering zone for cyclonic storm surges. The country, like Bangladesh needs geen vegetation belt along the coastal areas to reduce the magnitudes of deadly storm surges that hit the country almost every year. In this study, the effectiveness of coastal vegetation bio-shield in reducing storm surge effect has been studied through satellite image analysis, mathematical model simulation and laboratory experiment.

2.0 Methodology

The study is carried out using three different approaches for determining the efficiency of coastal vegetatuion in reducing strom surge energy. In first approach, a Arcview GIS 3.3 was used to digitize the images in satellite image analysis. Two SPOT images of 100 m resolution covering south-western coastal part of Bangladesh taken just before and after the SIDR were digitized with the Arc GIS software and the affected areas were calculated. The digitized images were compared to identify damages caused by the super cyclone SIDR and to study the effect of vegetation bio-shield. In second approach, a two dimensional hydrodynamic model named Bay of Bengal model developed by Institute of Water Modelling was applied for Sandwip island to investigate the effect of coastal vegetation in reducing the wave energy and current speed. The model was simulated for three conditions (i.e. 200m, 400m and 600m distance of vegetation barrier from the embankment) at the two specific points in the East side of the Sandwip island. In third approach, a two dimensional laboratory experiment was conducted in the Hydraulics and River Engineering Laboratory of Bangladesh University of Engineering and Technology to study the effect of distance of vegetation barrier in the reduction of wave height.

3.0 Satellite image analysis

Two satellite images on the 12th of November, 2007 and the 23rd of November, 2007 had been collected from CEGIS (Center for Environmental Geographical Information Services). The images were pre and post of cyclone SIDR occurred on the 15th November, 2007.

3.1 Data analysis and discussion

Satellite images were digitized with the help of Arc view GIS 3.3 software. JPEG image support had been used as extension. Lands and water areas were dessiminated by digitizing the images.Then lands and water areas were given IDs seperately. Finally the total affected area had been calculated and accumulated the areas (Table 1). Figure 1 and Figure 2 show the digitized lands with ID before and after the SIDR respectively.

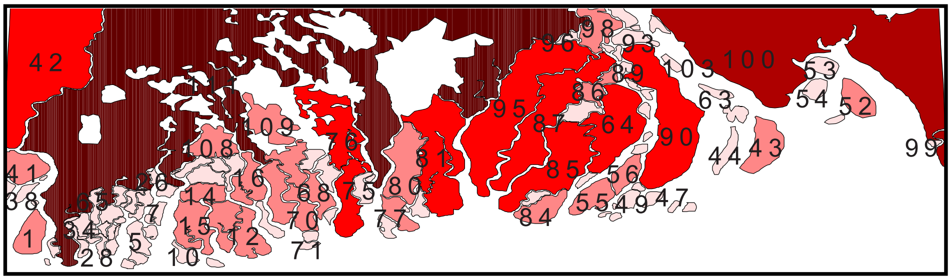


Fig. 1. Digitized land with ID before SIDR (Nov.12, 2007)

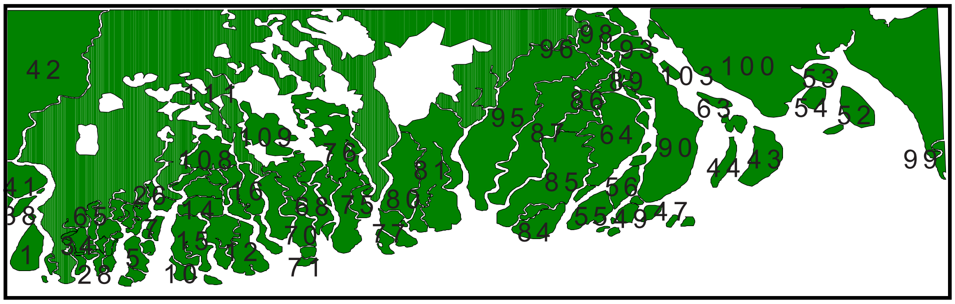


Fig. 2. Digitized land with ID after SIDR (Nov.23, 2007)

Table 1: Result of satellite image analysis

Items	Comparison			
	Nov 12, 2007	Nov 23, 2007	Difference	Comment
Total area of interest (Sq.unit)	1097892	1097892		
Total land area including vegetation (Sq.unit)	634539	606703	27836	Decrease
Total water area (Sq.unit)	463353	491189	27836	Increase

From the pie chart shown in Figure 3 below, it is seen that the total area of land including vegetation was 58% and total area of water was 42% before the SIDR. But the land area has decreased to 55% and the water area has increased to 45% just after the SIDR. That means 3% of area was damaged within the study area. It is observed from the images and various studies that the densely vegetated forest areas were less damaged than the exposed areas.

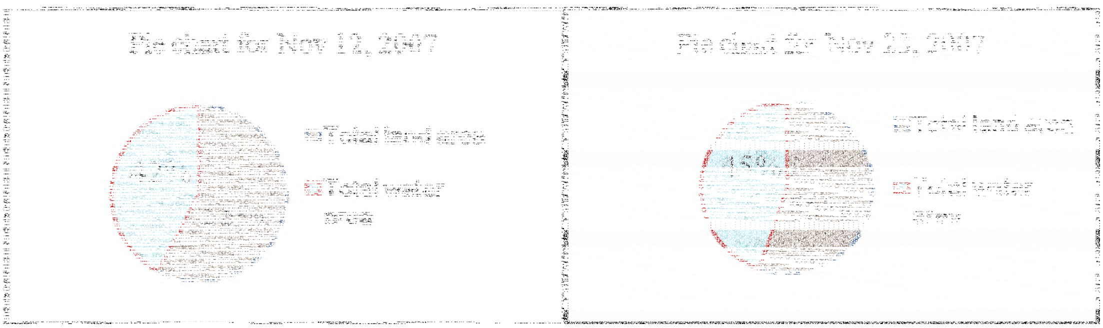


Fig. 3. Shows the changes of water and land area just before and after the SIDR

4.0 Numerical model simulation

The Sandwip island is an upazila under Chittagong district with an area of 762.42 sq km and the total population is 4,00,00 (source: Banglapedia) which is bounded by Bay of Bengal. The nearest mainland areas are Companiganj (Noakhali) upazila on the north, Sitakunda and Mirsharai upazilas on the east, Noakhali Sadar upazila, Hatiya Island and Meghna estuary on the west.

4.1 Model set-up

A two dimensional numerical model named Bay of Bengal Model (BoB) based on MIKE21 software developed by DHI water and Environment was used for the model simulation. The model area has been shown in the Figure 4. A model set-up on such a large area is necessary to include hydrological information moving from deep sea towards the Bangladeshi coastline as well as to reduce the boundary effect on the area of interest.

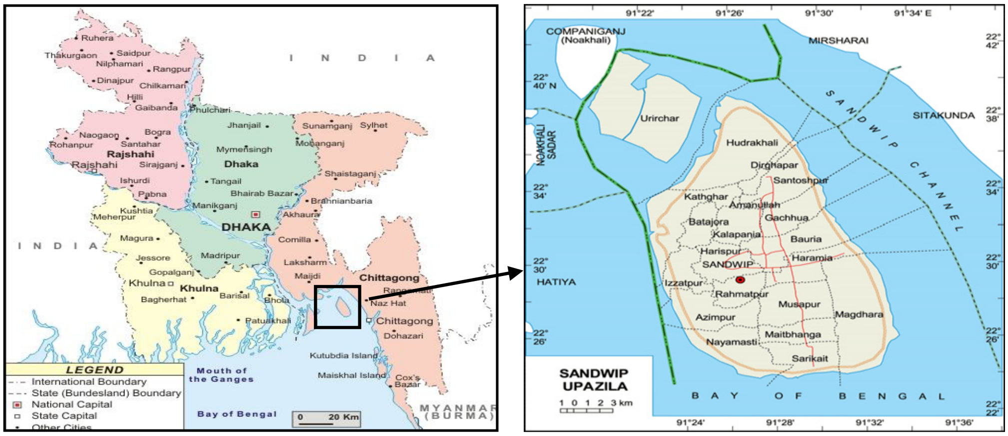


Fig. 4. Location of Sandwip Island

The base model covers the northern part of the Bay of Bengal from latitude 17°00′00″ to the coast of Bangladesh. The base model is a three way nested model and the resolutions are 5400m, 1800m and 600m. The Meghna Estuary is resolved on a 600m grid. Table 2 shows BoB model grid specification.

Table 2: BoB model grid specification

Model	Origin (degree)	Grid Spacing (m)	Grid Numbers	Length and Width
Coarse grid	Lon = 84.64 Lat = 18.91	$D_x = 5400$ $D_y = 5400$	180×93	972km × 502km
Intermediate grid	Lon = 86.75 Lat = 20.81	$D_x = 1800$ $D_y = 1800$	321×156	578km × 281km
Fine grid	Lon = 89.9712 Lat = 21.3393	$D_x = 600$ $D_y = 600$	396×357	238km × 214km

To investigate the impact of cyclonic storm surges on selected island properly, two local models of resolution 200m and 66.66m for Sandwip Island had been developed. The 66.66m resolution had been used for analysis and 200m resolution was used as intermediate to scale down from 600m resolution to 66.66m resolution. All the bathymetry data that were used to develop the Bay of Bengal model had been used to develop these local models. The table 3 shows grid specification of Sandwip island.

Table 3: Grid specification of Sandwip Local Model

Model	Origin (degree)	Grid Spacing (m)	Grid Numbers	Size of Model
Local Model Coarse	Long: 91.32 Lat: 22.28	200	181 X 211	36.2 km X 42.2 km
Local Model Fine	Long: 91.34 Lat: 22.31	66.66	451 X 541	30.0 km X 36.0 km

4.2 Model simulation

To observe the impact of distance from embankment three models have been simulated for Sandwip island.Three models are 200m, 400m and 600m from embankment and two specific points were considered at the east side of Sandwip island. The specific two pints are shown in the Figure 5.

Results from model simulation are furnished in the Table 4 and Table 5. It has been found that the water level remains almost same with increasing the distance of vegetation from the embankment. But the resulting velocity increases with increasing distance from the embankment.

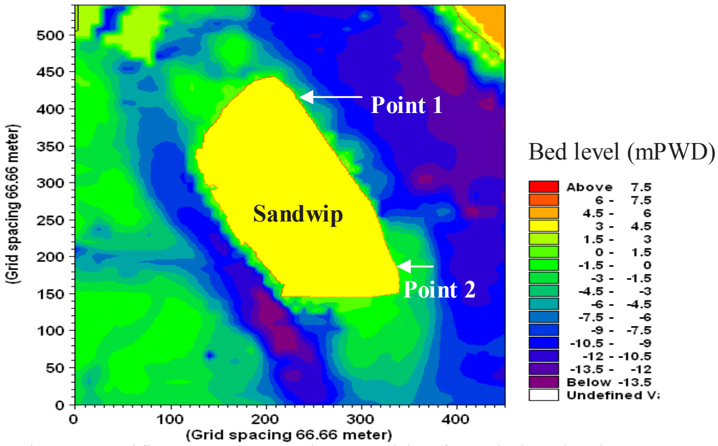


Fig. 5. Specific two points at the east side of Sandwip Island

Table 4: Model simulation results (at point 1)

Distance from Embankment(m)	Water level (mPWD)	Current Speed(m/s)	Change in surge height(cm) with 200m distance	Change in current Speed(m/s)
200	9.27	0.68		
400	9.25	0.92	- 2cm	+ 0.24m/s
600	9.26	1.03	-1 cm	+0.35 m/s

Table 5: Model simulation results (at point 2)

Distance from Embankment(m)	Water level (mPWD)	Current Speed(m/s)	Change in surge height(cm) with 200m distance	Change in current Speed(m/s)
200	9.4	0.44		
400	9.36	0.58	- 4cm	+ 0.14 m/s
600	9.35	0.76	- 5cm	+ 0.32 m/s

5.0 Laboratory experiment

To know the effects of vegetation barrier in reducing storm surges, a two dimensional laboratory experiment was performed in the Hydraulics and River Engineering Laboratory of Bangladesh University of Engineering and Technology.

*5.1 E*xperimental setup

Figure 6 shows the details of the experimental setup. The wave flume was 22 m long, 0.75 m wide and 0.75 m in height. The flume bed consisted of a relatively mild slope of 1:20, which had a length of 10 m. The effective horizontal length of the model bed was 20 m of the total flume length of 22 m. Vegetation (trees) was represented by cylindrical bamboo sticks whose diameter was 7 mm, the tree density was 361 sticks per unit area and the porosity was 0.9861. The vegetation model was 1m long in the wave propagation direction and 0.75m wide. There were three scenerios of experimental setup- the vegetation at 1m from the embankment, vegetation at 2m from the embankment and without vegetation. Figure 7(a) shows the plan view of wave flume with vegetation and Figure 7(b) depicts a plan view of the arrangement of cylindrical bamboo sticks that were used as vegetation barrier for this experiment. The bamboo sticks were placed on pre drilled concrete strips of 50mm width. Six measuring locations (1 to 6) were fixed to measure the temporal water surface elevation as shown in the above mentioned figures.

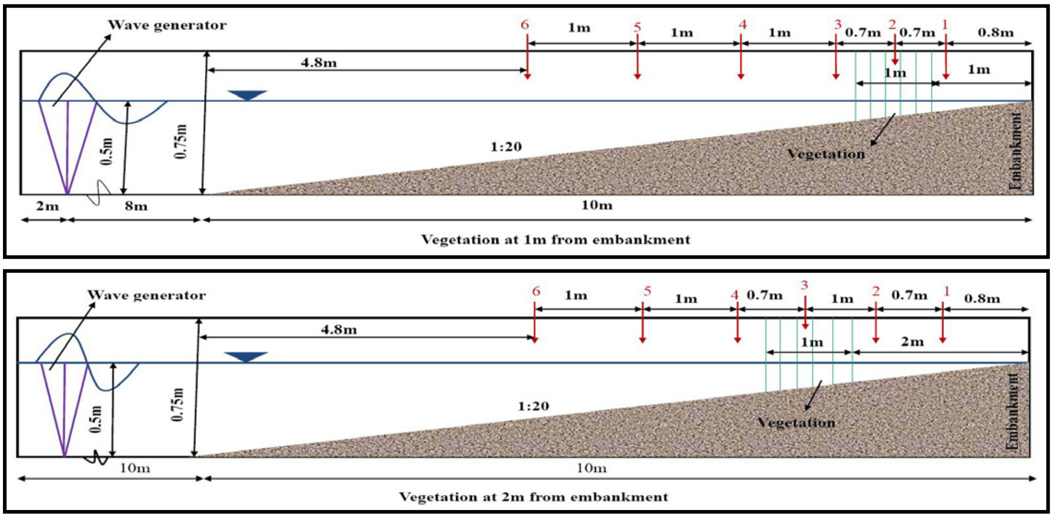


Fig. 6. Laboratory experiment setup

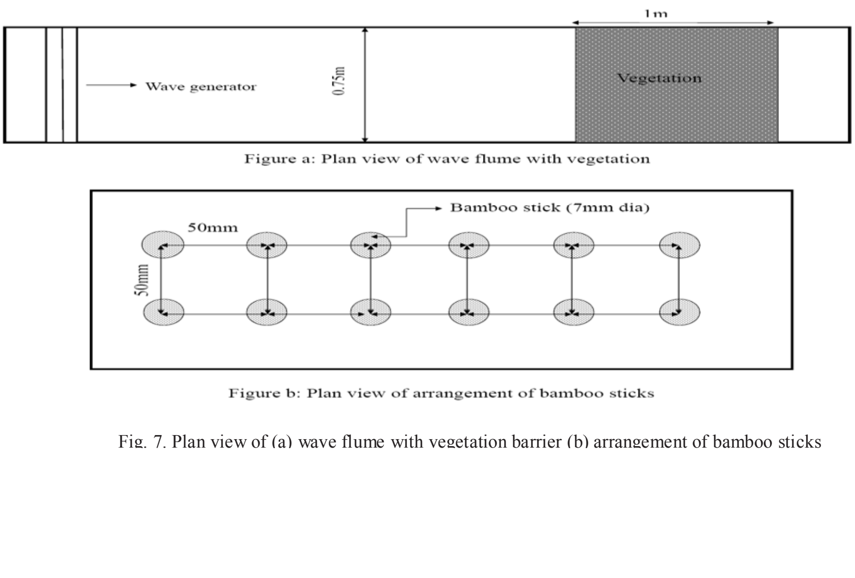


Fig. 7. Plan view of (a) wave flume with vegetation barrier (b) arrangement of bamboo sticks

5.2 Wave generator and vegetation barrier

There was a wave generator which was placed at one end of the large flume. Wave of desired wave period and wave height was set with the help of this wave generator.
A 1m long and 0.75m wide vegetation barrier has been used to study the effect of vegetation in reducing storm surge. The vegetation barrier acts as buffering zone which neutralizes the waves during cyclonic storm surge. The barrier was placed at two different positions i.e 1m and 2m from embankment. Figure 8 shows the pictures of vegetation barrier that has been used in this study.

Fig. 8. Vegetation barrier used in the Experimental study

5.3 Experimental run and data acquisition

Twelve experimental runs carried out in the laboratory are given in Table 6. Wave heights were measured before and after passing the vegetation barrier at 6 different locations. Measuring tapes were placed at 6 locations on the glass suface of the flume to measure the water level at 6 desired points. The point 1 is placed at 920cm, point 2 at 850cm, point 3 at 780cm, point 4 at 680cm, point 5 at 580cm and point 6 at 480cm from the starting point of the slope respectively. Point 1 was placed behind the vegetation zone, point 2 was placed within the barrier and the rest of the poitnts were placed in front of the vegetation barrier.

5.4 Experimental data analysis

Data obtained from this laboratory experiment are analyzed for various combination and the effect of vegetaton barrier is studied. Figure 8 shows the variation of water level with distance for wave period of 1.5 sec for the cases of vegetation barrier is placed at 1m and 2m from the embankment and without vegetation condition. From the Figure 9 it is observed that the wave height dcreases as it passes through the vegetation barrier because the barrier acts as a buffering zone when the waves pass through the vegetation barrier. Figure 10 shows the variation of wave height with distance from the starting point of the slope (1:20) for wave periods of 1.5 sec, 1.6 sec, 1.8 sec and 2.0 sec respectively. From the Figure 9 it is seen that the wave height decreases as it comes closer to the embankment, but the wave height is more reduced for vegetation barrier placed at 1m from the embankment than the wave height for vegetation barrier at 2m from the embankment.

Table 6: Experimental Run Condition

Run No	Wave Period(T)	Distance from Embankment	Water Depth	Thickness of Vegetation
1	1.5 sec	1m	50 cm	1m
2	1.6 sec	1m	50 cm	1m
3	1.8 sec	1m	50 cm	1m
4	2.0 sec	1m	50 cm	1m
5	1.5 sec	2m	50 cm	1m
6	1.6 sec	2m	50 cm	1m
7	1.8 sec	2m	50 cm	1m
8	2.0 sec	2m	50 cm	1m
9	1.5 sec	Without Vegetation	50 cm	1m
10	1.6 sec	Without Vegetation	50 cm	1m
11	1.8 sec	Without Vegetation	50 cm	1m
12	2.0 sec	Without Vegetation	50 cm	1m

The wave decreases in magnitude in two ways. The first way is the slopping effect which reduces the wave heights and the second way is the densely populated vegetation barrier which acts as buffering zone for the wave action. The waves reduces more in magnitude just behind the vegetation barrier. The effect of distance from the embankment is most obvious for vegetation placed at 1m from the embankment. So the vegetation should be planted near the embankment as thick as possible to protect the hinterland against cyclones and storm surges.

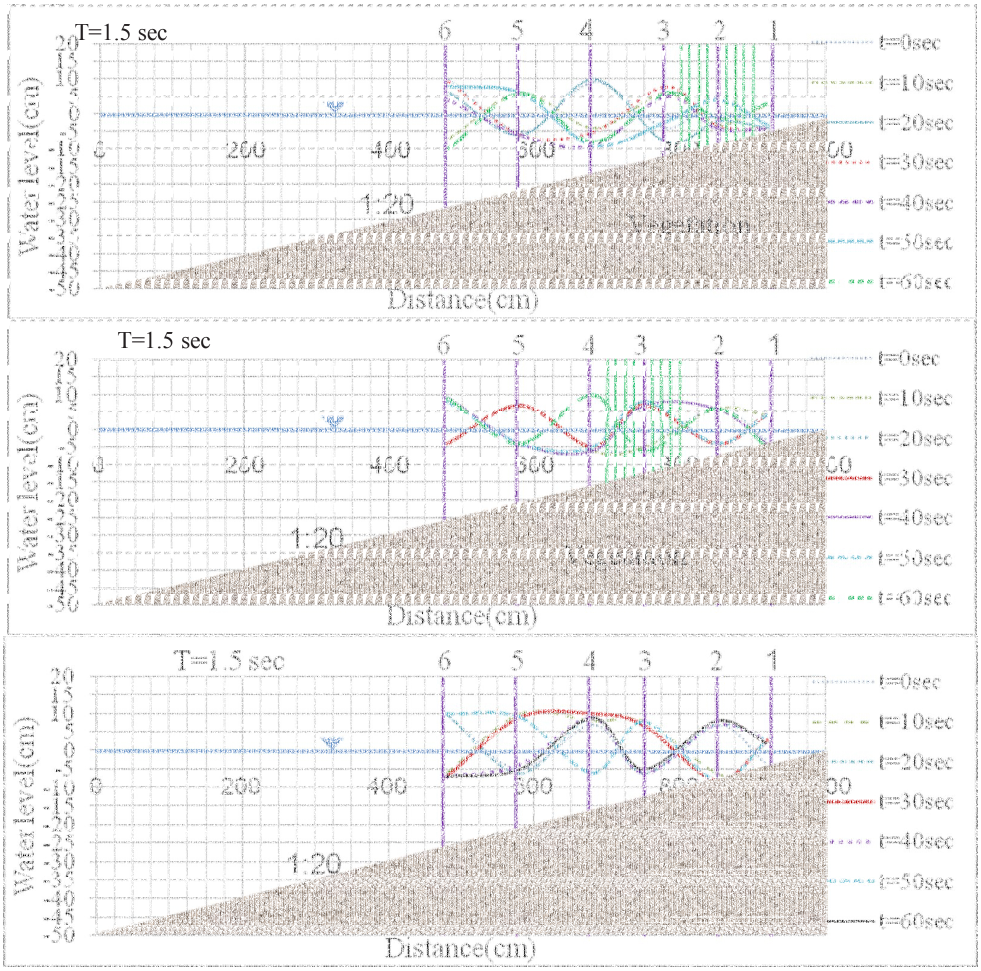
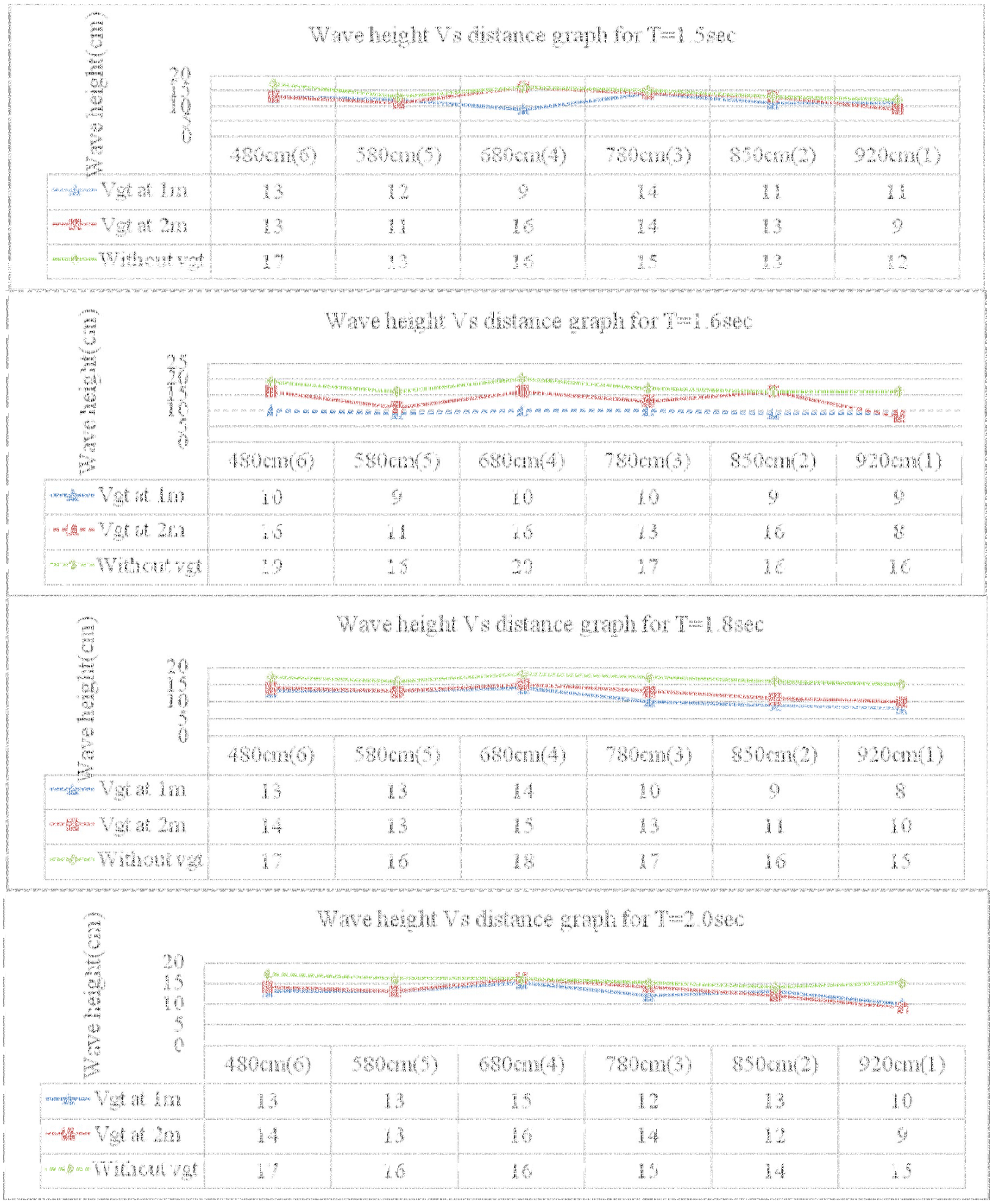


Fig. 9. Variation of water level with distance for different times (T=1.5 sec)

6.0 Conclusion

The coastal zone of Bangladesh is being impacted every year by cyclones and storm surges, coastal flooding and tidal surge. To reduce the effect of these disasters, a green belt of coastal vagetation could be the solution. In this study three different types of investigations have been carried out to understand the effect of coastal vegetation in reducing the energy of cyclones and storm surges, which are satellite image analysis, numerical model simulation and laboratory experiment. The satellite image analysis shows that the coastal areas of Bangladesh was less damaged where there were vegetation belt than the exposed areas without vegetation caused by the cyclone SIDR occured on the 15th of November, 2007. The two dimensional hydrodynamic model which was applied on Sandwip island shows that coastal vegetation has a great effect in the reduction of storm surges. Three models were simulated to investigate the effect of distance of coastal vegetation. The models were 200m, 400m and 600m distance of vegetation from the embankment. The models were simulated for two specific points on the East side of Sandwip island. At point 1 the water levels were 9.27m, 9.25m and 9.26m PWD and current speeds were 0.68 m/s, 0.92 m/s and 1.03 m/s for 200m, 400m and 600m distance of vegetation from embankment. At point 2 the water levels were 9.4m, 9.36m and 9.35m PWD and current speeds were 0.44 m/s, 0.58 m/s and 0.76 m/s for 200m, 400m and 600m distance of vegetation from embankment. The vegetation placed at 200m from the embankment is found to be the most effective barrier in reducing current speed. The Laboratory test was conducted for three conditions, these were 1m and 2m distance of vegetation from the embankment and without vegetation for 1.5 sec, 1.6 sec, 1.8 sec and 2.0 sec of wave periods. The test result shows that the vegetation barrier was the most effective in reduction of wave height for 1.6 sec of wave period. The vegetation barrier reduced the wave height up to 46% behind the barrier, 43% within the barrier and 41% in front of the barrier for 1.6 sec of wave period. It was observed during the experiment that the vegetation barrier acted as buffering zone for the incoming surge waves. Vegetation planted far away from the embankment has less significant effect in storm surge reduction. The thickness of the vegetation barrier is also an important factor for reduction of energy cyclones. A densely populated forest is the best barrier for the reduction of energy of any kind of natural disaster to protect the hinterland.



T=1.5sec

	480cm(6)	580cm(5)	680cm(4)	780cm(3)	850cm(2)	920cm(1)
Vgt at 1m	13	12	9	14	11	11
Vgt at 2m	13	11	16	14	13	9
Without vgt	17	13	16	15	13	12

T=1.6sec

	480cm(6)	580cm(5)	680cm(4)	780cm(3)	850cm(2)	920cm(1)
Vgt at 1m	10	9	10	10	9	9
Vgt at 2m	16	11	16	13	16	8
Without vgt	19	16	20	17	16	16

T=1.8sec

	480cm(6)	580cm(5)	680cm(4)	780cm(3)	850cm(2)	920cm(1)
Vgt at 1m	13	13	14	10	9	8
Vgt at 2m	14	13	15	13	11	10
Without vgt	17	16	18	17	16	15

T=2.0sec

	480cm(6)	580cm(5)	680cm(4)	780cm(3)	850cm(2)	920cm(1)
Vgt at 1m	13	13	15	12	13	10
Vgt at 2m	14	13	16	14	12	9
Without vgt	17	16	16	15	14	15

Fig. 10. Variation of wave height with distance for three different scenerios

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